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13. ABSTRACT (Maximum 200 words)

The use of propylene glycol (PG) base antifreeze in military vehicles is examined. Two approaches of adopting PG antifreeze into military maintenance practices are studied. The approaches include the use of a design specification and the use of a performance specification. For the design approach, a prototype PG antifreeze is field tested in several military vehicles. For the performance approach, five (5) commercial PG antifreezes are subjected to standard laboratory tests.

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Table of Contents

Propylene Glycol Antifreeze Study

I. INTRODUCTION

Background

In April 1991, after recognizing a growing number of restrictive state and federal legislation affecting ethylene glyco (EG) usage, the Defense General Supply Center (DGSC) requested the Mobility Technology Center-Belvoir (MTC-B), formally part of the now dis-established Belvoir Research, Development, and Engineering Center (BRDEC), to develop a less toxic antifreeze[1]. This effort was initiated under DGSC's Hazardous Waste Minimization Program. Prior to DGSC's request for assistance, the U.S. Army Construction Engineering Research Laboratory (CERL) had been requested by DGSC to identify alternative base fluids to EG. CERL identified four (4) less hazardous alternatives to EG. The alternatives included propylene glycol/water, dipropylene glycol/ water, 1,3-butylene glycol (with and without water), and dimethyl siloxane (silicone oil). From the CERL list, as well as past knowledge of heat transfer fluids, MTC-B chose propylene glycol/water mixture (PG) as the most viable alternative antifreeze. PG was chosen because of its similar properties to EG as well as its previously established automotive application of use in the U.S. and abroad[2].

The need for an alternative antifreeze was established because of increasing state and federal legislation placing additional restrictions in handling, use and disposal of EG base antifreeze due to its relatively high toxicity towards mammals. For example, EG is federally regulated by the Occupational Safety and Health Administration (OSHA) based on Threshold Limit Values (TLV's) for hazardous chemical substances in workroom air. In 1991, EG was added to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) toxic air pollutants list from the 1990 Clean Air Act. This act required users to report spills of one (1) pound or more. The one pound limit was changed to 5000 pounds in July 1995 which alleviated most concerns of organizations using small to moderate amounts of EG base fluids. However, the addition of EG to the list was a significant impetus for a less toxic, alternative antifreeze and is still of concern for organization utilizing large quantities of EG antifreeze.

At the state level, the State of California considers new, unused EG antifreeze solutions hazardous due to EG's toxicity towards humans and other mammals. In 1992 the state of California established taste aversant requirements for sixteen consumer items, which included EG antifreeze, that are potentially harmful to humans by ingestion. Because of California's strong concern over EG toxicity it was expected that other states would follow suit. For example, the state of Oregon, as of 30 April 1995, requires taste aversants in EG base antifreezes. These present and expected future state and federal regulations invariably add to the cost of operation and bring extra burdens to military installations and those civilian agencies utilizing EG antifreezes.

Having a substitute PG antifreeze ready for use will help reduce the number of problems and offer an alternative for agencies interested in reducing environmental risks while at the same time, increasing worker safety.

Objective

The objective of the study was to develop an alternative antifreeze which would be used as a less toxic substitute for the EG base antifreeze, MIL-A-46153[3] required for all military combat/tactical materiel.

II. INVESTIGATION

Approach

After establishing the most practical base fluid for an alternative antifreeze to be PG, both design and performance specifications were initially considered as parallel approaches for development of the desired PG antifreeze. For the design standard or detail specification, original formulations for the PG antifreeze were examined. The detail specification would be similar to the current MIL-A-46153 specification where the exact PG formulation would be described. For this approach, several experimental prototype PG formulations were developed and evaluated employing the performance and quality tests described in Table 1.

For the performance specification approach, commercially available PG antifreezes were investigated. This investigation involved testing commercial PG antifreeze products to determine their possible use in a performance specification such as the Commercial Item Description (CID), A-A-870 for EG base, automotive antifreeze[4]. Standard laboratory antifreeze tests from American Society for Testing and Materials (ASTM) 1991 Annual Book of Standards[5], along with one (1) non-ASTM test were employed to assess the overall feasibility of developing a performance standard for PG military antifreeze. The performance and compatibility tests are shown in Table 1.

Design Specification Experimental

Several prototype PG base antifreeze formulations were prepared and tested. These formulations were based on the current MIL-A-46153 EG antifreeze formula, the formulation specified in General Motors' EG antifreeze, GM 6038M[6], and information obtained from various literature sources concerning corrosion inhibitors for EG and PG antifreezes.[7,8,9,10,11,12,13,14] For example, from MIL-A-46153, borax and phosphate inhibitors were employed for pH control and antirust for cooling system components containing iron. For copper containing components, sodium tolytriazole (NaTT) and disodium 2,5-dimercapto-1,3,4-thiadiazole (Na_2DiMTD) were included. Na_2DiMTD was a new copper corrosion inhibitor discovered during the time of this investigation. The Na_2DiMTD was examined to determine any solubility and/or corrosion protection advantages over the commonly used sodium mercaptobenzothiazole (NaMBT) and

NaTT. For specific protection of wet sleeve liners found in diesel engines, sodium nitrite was included. Sodium silicate and sodium nitrate were included for protection of aluminum containing components. The prototype formulations including the MIL-A-46153 formulation are shown in Tables 2-3.

Preparation of the prototype formulations involved initially adding borax to the glycol with continuous stirring and heating at temperatures between 50° and 60°C. The remaining inhibitors were introduced via the required distilled water diluent using continuous stirring and heating at temperatures between 40° and 55°C. Because of the known instability of mercaptobenzothiazole (MBT) to light and air[15,16], Na_2DiMTD (a chemical derivative of MBT) was tested for stability in formulations PG#1 and PG#2. To examine the Na_2DiMTD stability, watch glass covered, 400-mL glass beakers containing experimental formulations PG#1 and PG#2 (200mL) were placed in direct sunlight for three (3) days. Each watch glass did not completely seal the beaker and allowed air to enter through the beaker spout. A yellow-white precipitate was observed on the third day indicating instability of the Na2DiMTD. In addition, these formulations PG#1 and PG#2 failed the glassware corrosion test (ASTM D1384) with excessive weight loss evidenced for the brass coupons for each. The use of Na_2DiMTD was abandoned as a result of these findings.

Formulations PG#4, PGL5, and PGL6 all produced precipitates during preparation and were excluded from further examination. Formulations PGL1, PGL2, and PGL4 had pH values that were considered too high for corrosion protection purposes. For example, a pH above 11 for a 50-50 aqueous solution is considered high and could cause corrosion problems[17]. Formulations PGL3 and PGL7 were determined stable enough for further examination. However, because of allowable time and funding constraints, only formulation PGL7 was performance tested using two (2) tests. The PGL7 successfully passed ASTM performance tests D1384 (Corrosion Test for Engine Coolants in Glassware) and D4340 (Corrosion of Cast Aluminum Alloys in Engine Coolants Under Heat-Rejecting Conditions). The remaining ASTM performance tests to verify the performance of formulation PGL7 were not conducted. To expedite the development of a military PG antifreeze, MTC-B and ARCO Chemical Company, the US major producer of raw PG, jointly developed a heavy duty PG formulation for combat/ tactical vehicles and heavy equipment use. After receiving the target military requirements and information generated by these initial studies, ARCO provided the PG candidate antifreeze formulation described in Table 4. The ARCO military formulation was based on a previously laboratory and field tested ARCO formulation[18] as well as that information generated by MTC-B. Because of the successful experience with the original ARCO formulation, the modified military formulation was determined acceptable for field testing. To validate the performance of the military PG formulation in an operational environment, a one (1) year vehicle field demonstration was conducted.

For the field demonstration, Ft Bliss TX was chosen as the test site because of the temperate to hot climate and because of the successful cooperation of Ft Bliss in conducting demonstrations. The demonstration was a non-impact type cooperative test

designed to not interfere with the Ft Bliss's mission objective. The 6th Air Defense Artillery Brigade (ADAB) volunteered sixteen (16) combat/tactical vehicle for the year long demonstration. The 6th ADAB is a training unit where vehicles usually received low mileage and moderate to high number of idling hours. This type of vehicle usage was particularly severe on the engine antifreeze during the summer season. Each summer produced several consecutive days with temperatures above 100°F. A list of the test vehicles and their service duties are shown in table 5. Most vehicles were manufactured and delivered for service between 1982 and 1987. Two (2) Bradley Fighting Vehicles (i.e, M3) that were manufactured in 1992 were fairly new and had only been in service two (2) months. One (1) vehicle, a 5-Ton Wrecker Truck, had a 1967 manufacturing date. All vehicles had cast iron water pumps, engine blocks, and cylinder heads, and brass/copper radiators. A few vehicles utilized aluminum alloy thermostat housings. Eight (8) of the test vehicles had original antifreeze that was murky in appearance, but only two (2) vehicles had antifreeze that contained rust. The test candidate PG antifreeze and control antifreeze MIL-A-46153 were prepared with distilled water. After the initial drain and flush, each vehicle's test antifreeze was partially diluted because of leftover flush water as indicated by comparison of Tables 6 and 8. Because of the non-impact nature of the demonstration, these dilutions were not considered significant to adversely affect the demonstration results.

The determination of the performance capabilities of the candidate PG antifreeze was accomplished by comparing selected properties and 6th ADAB vehicle reports of the candidate PG antifreeze with the control base antifreeze, MIL-A-46153. The properties included pH, reserve alkalinity (RA), and trace metal content. Small samples (250mL) of antifreeze from each vehicle were collected and examined quarterly. The 6th ADAB vehicle reports were also examined each quarter. Results of the antifreeze property analyses are shown in Tables 8 through 11. Results show fluctuations in antifreeze concentrations as indicated by the varying freeze points. These fluctuations were attributed to normal vehicle operation and 6th ADAB personnel "topping off" with tap water and/or new MIL-A-46153 antifreeze as necessary in the field. Despite these fluctuations, no vehicle failures or antifreeze related problems were recorded or observed by 6th ADAB personnel for vehicles containing the candidate PG antifreeze. Test vehicle #14, which contained control antifreeze (MIL-A-46153), was removed from the demonstration because of a non-antifreeze related engine failure. Overall conclusion drawn from the demonstration data collected and the experiences of 6th ADAB personnel indicated that the candidate PG military formulation antifreeze performed satisfactorily with no abnormalities being observed. ARCO examined depletion rates of the test antifreeze's corrosion inhibitors and determined that based on their previous experience, the inhibitors were depleted at a normal rate indicating no excessive corrosion problems to be anticipated.

Performance Specification Experimental

Five (5) commercially available PG antifreezes were examined. The PG antifreezes and their manufacturer included (1) Sta-Clean (Sta-Clean Products Inc), (2) Uni-Gard (Monson Chemicals), (3) Compleat (Fleetguard Inc), (4) Eco-III (OMNI

Industries), and (5) Tundra (ARCO Chemical Co). These PG antifreezes were randomly selected from a commercial PG antifreeze manufacturer list developed through MTC-B industry contacts. The PG antifreezes were examined for performance and compatibility with each other and MIL-A-46153 antifreeze. During past MTC-B investigations[19,20], chemical incompatibility problems when mixing different brands of commercial antifreezes have been observed and documented. This incompatibility was usually caused by incompatible corrosion inhibitors or over-concentration of similar inhibitors. Incompatibility of antifreeze mixtures can cause increased corrosion and precipitates which lead to abrasion damage and/or plugging. Compatibility testing for this PG study was considered important because a PG performance standard would allow different brands of PG antifreeze to be mixed with each other as well as MIL-A-46153 during normal field use. The compatibility test consisted of mixing equal amounts of two concentrates and diluting with distilled water so the resultant solution was approximately a 50-50 mixture. The solution was allowed to stand overnight at room temperature and then examined for any occurrence of precipitates. The solution was then placed in an oven at 55°C for one (1) hour and once again examined for precipitates. The solutions were shaken by hand approximately 25 seconds and then allowed to remain undisturbed for four (4) additional days. Finally, the samples were placed in an oven at 75° for one (1) hour and again examined for precipitates. After subjecting all possible combinations of the PG samples and MIL-A-46153 to this test, the results subsequently obtained were as shown in Table 13. Incompatibility was evidenced by the formation of a precipitate or any phase separations. The results revealed the majority of the commercial PG antifreezes examined were incompatible with each other (i.e., 7 failing out of 10 possible combinations) as well as with MIL-A-46153, respectively.

To determine if the five (5) PG commercial antifreezes could meet minimum industry performance requirements, each PG antifreeze was subjected to four (4) ASTM standard laboratory tests. The tests included D1384 (Corrosion Test for Engine Coolants in Glassware), D1881 (Foaming Tendencies of Engine Coolants in Glassware), D2809 (Cavitation Erosion-Corrosion of Aluminum Pumps with Engine Coolants), and D2570 (Simulated Service Corrosion Testing of Engine Coolants). Tests D1881 and D1384 were conducted in-house at MTC-B. Tests D2570 and D2809 were conducted by an independent laboratory, Southwest Research Institute in San Antonio TX. To judge the performance, the test results were compared against the minimum requirements[21] of ASTM specifications D3306 for Ethylene Glycol Base Engine Coolant for Automobile and Light Duty Service, D4985 for Prediluted Aqueous Ethylene Glycol base Low-Silicate Engine Coolant (50 Volume Percent Minimum) for Heavy-Duty Engines Requiring an Initial Charge of Supplemental Coolant Additive, and D5216 for Propylene Glycol Base Engine Coolant for Automobile and Light-Duty Service. The test results are shown Tables 14a through 15b. As indicated by the performance test results, each of the commercial PG antifreezes examined failed one or more of these important performance tests.

Results and Discussion

From this investigation, two (2) potential military prototype, PG base antifreezes were produced (i.e., PGL3 and PGL7); however, additional research would be required to fully confirm their performance. In addition, a PG formulation was shown to perform acceptably under temperate to warm weather conditions in military combat/tactical vehicles. The success of the ARCO PG formulation at Fort Bliss TX has led to additional funding being provided by DGSC to further evaluate the ARCO formulation under extreme cold weather conditions in Alaska. A parallel field demonstration has been recently initiated at Ft Wainwright AK and is scheduled to be completed December 1997. If the Alaskan PG demonstration is successful, a detailed specification could be developed for use by the end of 2Q FY1997 or later.

The performance and compatibility test results of the five (5) commercial PG antifreezes examined were poor. The performance results reflect the relatively small formulation experience some U.S. antifreeze manufacturers have with PG. A performance specification could be developed which would only allow the use of acceptable PG commercial antifreeze products. In addition, it would be essential to incorporate the compatibility test developed during this study or a similar test into the performance specification to guarantee good field performance when different antifreeze brands are inadvertently mixed.

III. CONCLUSIONS

Disodium 2,5-dimercapto-1,3,4-thiadiazole (Na_2DiMTD) was determined unsuitable as a substitute copper inhibitor for sodium mercaptobenzothiazole (NaMBT) and sodium tolytriazole (NaTT) in PG antifreeze. Na_2DiMTD exhibited instability characteristics (i.e., precipitate formation) similar to those observed for NaMBT in past EG antifreeze studies

Because of the collaborative efforts of MTC-B and the ARCO Chemical Company a candidate PG antifreeze for heavy duty military vehicle use was developed and successfully field tested. The use of PG antifreeze in military vehicles, under warm weather conditions was shown to be possible without any elaborate modifications to vehicles or customary vehicle maintenance practices.

A commercial brand PG antifreeze may not always meet the standard ASTM performance requirements claimed by the manufacturer. If a government PG performance specification or commercial PG performance standard is adopted, random product sampling will be required to insure performance in the field. These product quality checks should be required as part of the procurement contract.

An antifreeze compatibility test for examining different PG antifreeze brands can be used to determine incongruous antifreeze combinations.

At present there are at least three (3) major engine antifreeze product manufacturers (i.e., Fleetguard, Grace Dearborn, and Penray), with multi-vehicle type formulations for EG base antifreezes. Despite the marginal quality of the commercial PG antifreeze sampled in this report, it is believed that these companies have the capability to formulate acceptable PG base antifreeze equivalents.

IV. RECOMMENDATIONS

The performance test results of five (5) commercially available PG antifreezes with standard ASTM tests were marginal. Each of the five antifreezes failed at least one (1) ASTM test. Despite the poor performance and limited inter-brand compatibility, a performance specification for military procurement is still considered feasible and recommended. At present a cold weather field demonstration of the ARCO candidate PG formulation is being tested. As such a final recommendation cannot be giving until the demonstration is completed in December 1997. However, assuming the results are successful, it is recommended that a performance specification be developed to allow inter-brand use as well as have multi-vehicle type applications (e.g., heavy and light duty).

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21. Because of the uniformity of ASTM coolant standards the minimum requirement for each specification are identical, but are listed here for comparison.

TABLE 1.
Laboratory Tests

Performance Tests

- Foaming Tendencies of Engine Coolants in Glassware (ASTM D1881)
- Corrosion Test for Engine Coolants in Glassware (ASTM D1384)
- Cavitation Erosion-Corrosion of Aluminum Pumps with Engine Coolants (ASTM D2809)
- Simulated Service Corrosion Testing of Engine Coolants (ASTM D2570)

Quality Tests

- Reserve Alkalinity (RA) of Engine Antifreeze, Antirusts, and Coolants (ASTM D1121)
- pH of Engine Antifreezes, Antirusts, and Coolants (ASTM D1287)
- Use of The Refractometer for Determining the Freezing Point of Aqueous Engine Coolants (ASTM D3321)

Compatibility Test

- In-House Compatibility Test (non-ASTM)

TABLE 2.
PG Prototype Formulations
mass percent

	MIL[1]	PG#1	PG#2	PG#3	PG#4
Borax ($Na_2B_4O_7 \cdot 10H_2O$)	4.00	4.00	2.00	4.00	2.50
Trisodium Phosphate ($Na_3PO_4 \cdot 12H_2O$)	0.30	0.30	0.30	0.30	0.50
Sodium Nitrate ($NaNO_3$)	0.00	0.20	0.20	0.00	0.30
Sodium Nitrite ($NaNO_2$)	0.00	0.20	0.20	0.00	0.30
Sodium Tolytriazole (NaTT, 50% aq soln')	0.25	0.00	0.00	0.25	0.30
Sodium Dimercaptobenzo-thiadiazole (Na_2DiMTD)	0.00	0.20	0.20	0.00	0.00
Sodium Silicate ($Na_2SiO_3 \cdot 9H_2O$)	0.00	0.30	0.30	0.00	0.50
Sodium Hydroxide (NaOH)	0.00	0.30	0.00	0.00	0.10
Antifoam (Pluronic L-61)	0.03	0.03	0.03	0.03	0.02
Added Water	2-5	5.00	5.00	2.60	2.00
PG	0.00	89.67	91.97	92.82	93.48
pH Concentrate	6.1	6.6	6.6	6.4	nt[2]
RA Concentrate, mL	25.2	27.2	16.1	26.2	nt
pH 50-50 Aq Soln'	7.7	7.7	7.7	7.6	nt

[1] "MIL" - MIL-A-46153 antifreeze
[2] "nt" - not tested

TABLE 3.
PG Prototype Formulations
mass percent

	PGL1	PGL2	PGL3	PGL4	PGL5	PGL6	PGL7
Borax ($Na_2B_4O_7 \cdot 10H_2O$)	1.00	1.00	1.00	0.00	1.00	2.50	2.50
Trisodium Phosphate ($Na_3PO_4 \cdot 12H_2O$)	0.60	0.60	0.00	0.60	0.60	0.50	0.30
Sodium Molybdate ($Na_2MoO_4 \cdot 2H_2O$)	0.00	0.00	0.60	1.00	0.00	0.00	0.00
Sodium Nitrate ($NaNO_3$)	0.50	0.30	0.30	0.30	0.25	0.30	0.30
Sodium Nitrite ($NaNO_2$)	0.50	0.30	0.30	0.30	0.25	0.30	0.30
Sodium Tolytriazole (NaTT, 50% aq soln')	0.25	0.25	0.25	0.25	0.25	0.30	0.30
Sodium Silicate ($Na_2SiO_3 \cdot 9H_2O$)	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium Hydroxide (NaOH)	0.40	0.20	0.10	0.10	0.10	0.10	0.10
Antifoam (Pluronic L-61)	0.02	0.02	0.02	0.02	0.02	0.02	0.20
Added Water	2.0	2.0	2.0	2.0	2.0	2.0	2.0
PG	94.43	95.03	95.13	95.13	95.23	93.68	93.70
pH Concentrate	12.9	11.7	9.2	12.8	nt	nt	6.3
RA Concentrate, mL	23.6	17.7	11.4	11.0	nt	nt	22.2
pH 50-50 Aq Soln'	2.2	11.7	8.9	12.1	nt	nt	8.0

TABLE 4.
ARCO PG Formulation
mass percent

	ARCO
Borax Pentahydrate ($Na_2B_4O_7 \cdot 5H_2O$)	0.84
Benzoic Acid (C_6H_5COOH)	2.30
Sodium Nitrate ($NaNO_3$)	0.11
Sodium Nitrite ($NaNO_2$)	0.12
Solid Tolytriazole (TT)	0.25
Sodium Silicate ($Na_2SiO_3 \cdot 5H_2O$)	0.20
AF-1 silicate stabilizer	0.14
Sodium Hydroxide (NaOH)	0.96
Antifoam (Pluronic L-61)	0.025
Added Water	2.00
PG	93.055
pH Concentrate	10.2
RA Concentrate, mL	14.2
pH 50-50 Aqueous Soln'	10.4

TABLE 5.
Vehicle Usage Profile[1]

Vehicle (Engine)	"Usually Employed To"
1. M978 10-Ton Fuel Servicing Truck (8V92TA)	Fuel other vehicles in the field
2 M923 Cargo Truck (NHC 250)	Pickup personnel & supplies, escort tracked vehicles
3. M730A2 GM Carrier (Chaparral) (DD6V53)	Training vehicle
4. M1038ww 1 1/4-Ton Cargo Truck (GM6.2L)	General purpose, pickup supplies & personnel
5. M998 1 1/4-Ton Cargo Truck (GM6.2L)	General purpose/pickup supplies/personnel
6. M3 Bradley Fighting Vehicle (VTA-903T)	Training vehicle
7. M983 10-Ton Tractor Truck (8V92TA)	Training vehicle
8. M985 Cargo Truck with Crane (8V92TA)	Move heavy equipment in the field
9. M1028A1 1 1/4-Ton Cargo Truck (GM6.2L)	General purpose/pickup supplies/personnel
10. M813 5-Ton Fuel Servicing Truck (NHC 250)	Fuel other vehicles in motor pool
11. M543A2 5-Ton Wrecker Truck (LDS4654)	Move heavy equipment in the field
12. **M2 Bradley Fighting Vehicle (VTA-903T)**	**Training vehicle**
13. **M1009 3/4-Ton Utility Truck (GM6.2L)**	**General purpose/pickup supplies/personnel**
14. **M1009 3/4-Ton Utility Truck (GM6.2L)**	**General purpose/pickup supplies/personnel**
15. **M35A2 2 1/2-Ton Cargo Truck (LD465-1) tracked vehicles**	**Pickup personnel & supplies, escort**
16. **M730A2 GM Carrier (Chaparral) (DD6V53)**	**Training vehicle**

[1] Control vehicles filled with MIL-A-46153 antifreeze highlighted in bold.

TABLE 6.
Pre-Demo Antifreeze Characteristics

	pH	RA	Freeze Point	Metals, ppm Al	Fe	Cu	Pb
MIL-A-46153 50-50 aqueous	7.8	12.9mL	-32°F	<1	<1	<1	<1
PG Antifreeze 50-50 aqueous	10.4	7.3mL	-26°F	<1	<1	<1	<1

TABLE 7.
Initial Test Vehicle Mileage & Hours Data, Zero (0) Months

Vehicle	Mileage	Hours
1. M978 10-Ton Fuel Servicing Trk	10687	1398
2. M923 Cargo Trk	19281	790
3. M730A2 GM Carrier (Chaparral)	73	14
4. M1038ww $1^1/_4$-Ton Cargo Truck	6257	na[1]
5. M998 $1^1/_4$-Ton Cargo Truck	2429	na
6. M3 Bradley Fighting Vehicle	86	na
7. M983 10-Ton Tractor Truck	1762	793
8. M985 Cargo Truck with Crane	4881	2224
9. M1028A1 $1^1/_4$-Ton Cargo Truck	37011	na
10. M813 5-Ton Fuel Servicing Trk	334	3171
11. M543A2 5-Ton Wrecker Truck	411	159
12. M2 Bradley Fighting Vehicle	**119**	**na**
13. M1009 $^3/_4$-Ton Utility Truck	**21017**	**na**
14. M1009 $^3/_4$-Ton Utility Truck	**40167**	**na**
15. M35A2 $2^1/_2$-Ton Cargo Truck	**40022**	**703**
16. M730A2 GM Carrier (Chaparral)	**317**	**42**

[1] na - not applicable

TABLE 8.
FT BLISS PG FIELD DEMONSTRATION
pH, RA, AND FREEZE POINT (FP) VALUES AFTER ONE YEAR

Vehicle:	1	2	3	4	5	6	7	8
Month[1]								
pH-0	8.9	9.0	8.7	8.8	8.7	8.4	9.1	8.9
pH-3	8.8	8.5	8.7	8.7	8.6	8.4	8.8	8.9
pH-6	8.8	8.1	8.8	8.3	8.7	8.3	9.0	9.0
pH-9	9.2	8.3	9.0	8.1	8.8	8.2	9.2	9.3
pH-12	9.0	8.2	8.9	8.0	8.6	8.2	9.1	9.2
RA-0	6.5mL	6.5mL	6.0mL	6.1mL	5.5mL	6.1mL	7.0mL	6.2mL
RA-3	4.7mL	4.1mL	6.0mL	3.8mL	4.1mL	6.1mL	4.9mL	4.9mL
RA-6	5.7mL	6.0mL	6.7mL	5.6mL	4.7mL	6.2mL	6.9mL	5.8mL
RA-9	5.6mL	5.8mL	5.4mL	8.5mL	4.6mL	7.8mL	6.6mL	55.5mL
RA-12	5.5mL	4.8mL	5.4mL	8.3mL	4.5mL	7.7mL	6.3mL	5.5mL
FP-0	-25°F	-20°F	-17°F	-1°F	-7°F	-6°F	-30°F	-18°F
FP-3	-2°F	0°F	-17°F	8°F	4°F	-6°	-10°F	-9°F
FP-6	-8°F	-2°F	-8°F	2°F	4°F	-9°F	-21°F	-9°F
FP-9	-10°F	0°F	-8°F	-20°F	4°F	-19°F	-29°F	-10°F
FP-12	-10°F	8°F	-9°F	-21°F	3°F	-20°F	-30°F	-9°F

[1] "pH-3" - pH after 3 months of service.

TABLE 9.
FT BLISS PG FIELD DEMONSTRATION
pH, RA, and FREEZE POINT (FP) VALUES (cont'd)

Vehicle:	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Month								
pH-0	9.0	8.9	8.2	7.8	8.1	8.0	7.8	7.6
pH-3	8.7	8.5	8.2	7.8	8.1	8.1	7.8	7.8
pH-6	8.9	8.5	8.4	8.0	8.2		7.9	8.0
pH-9	8.6	8.8	8.6	8.2	8.3		8.1	8.1
pH-12	8.6	8.7	8.6	8.1	8.3		8.0	8.1
RA-0	3.2mL	5.7mL	7.2mL	9.7mL	6.2mL	6.2mL	9.4mL	12.9mL
RA-3	2.7mL	4.8mL	6.4mL	8.9mL	6.2mL	5.6mL	8.5mL	9.9mL
RA-6	3.0mL	6.0mL	6.4mL	9.5mL	6.5mL		9.8mL	11.4mL
RA-9	3.4mL	5.1mL	6.1mL	9.1mL	6.2mL		9.5mL	10.3mL
RA-12	3.4mL	5.0mL	3.4mL	9.0mL	5.9mL		9.6mL	9.8mL
FP-0	17°F	-10°F	-28°F	-7°F	11°F	11°F	-5°F	-30°F
FP-3	18°F	-8°F	-22°F	-8°F	11°F	12°F	-5°F	-12°F
FP-6	19°F	-3°F	-9°F	-9°F	9°F		-10°F	-12°F
FP-9	17°F	-3°F	-10°F	-8°F	10°F		-12°F	-15°F
FP-12	17°F	-4°F	-10°F	-8°F	10°F		-14°F	-10°F

TABLE 10.
FT BLISS PG FIELD DEMONSTRATION
TRACE METAL[1] VALUES AFTER ONE YEAR, ppm

Vehicle:	1	2	3	4	5	6	7	8
Month								
Fe-0	1.0	1.1	10.0	2.0	4.7	2.7	1.0	1.4
Fe-3	1.7	2.8	3.8	<1	4.1	<1	3.7	2.0
Fe-6	1.2	3.2	4.5	<1	5.1	<1	1.0	2.7
Fe-9	1.0	8.8	8.6	<1	19.1	<1	1.4	2.3
Fe-12	1.1	2.1	3.8	2.0	26.0	<1	2.1	<1
Pb-0	<1	<1	2.4	<1	1.0	7.3	5.5	1.0
Pb-3	<1	1.6	6.6	<1	1.2	<1	66.2	33.3
Pb-6	1.0	3.9	9.3	1.0	5.4	1.3	4.1	34.8
Pb-9	1.0	8.6	12.2	<1	7.2	1.1	8.1	<1
Pb-12	1.2	23.0	14.5	1.0	20.0	<1	5.5	<1
Al-0	<1	<1	<1	1.0	<1	3.3	1.0	<1
Al-3	<1	<1	<1	<1	1.2	1.0	<1	5.4
Al-6	<1	<1	1.0	<1	1.0	1.0	<1	9.7
Al-9	<1	<1	1.0	<1	1.2	1.0	<1	10.7
Al-12	<1	<1	1.4	<1	6.6	<1	<1	<1
Cu-0	<1	<1	<1	<1	<1	<1	<1	<1
Cu-3	<1	1.7	<1	<1	<1	<1	1.0	<1
Cu-6	<1	<1	<1	<1	<1	<1	<1	1.0
Cu-9	<1	1.0	<1	<1	<1	<1	<1	1.0
Cu-12	<1	2.1	1.0	<1	1.0	<1	<1	<1

[1] Fe = Iron, Pb = Lead, Al = Aluminum, Cu = Copper

TABLE 11.
FT BLISS PG FIELD DEMONSTRATION (cont'd)
TRACE METAL VALUES

Vehicle:	9	10	11	12	13	14	15	16
Month								
Fe-0	2.0	12.0	2.6	2.0	2.0	2.0	3.6	1.4
Fe-3	2.9	225	2.9	1.5	3.0	<1	<1	2.0
Fe-6	<1	20.8	1.0	1.0	2.1		2.2	2.7
Fe-9	<1	53.0	1.0	1.0	1.4		1.1	2.3
Fe-12	<1	200	1.0	<1	<1		<1	3.0
Pb-0	14.0	<1	8.4	1.0	1.0	3.0	1.4	1.0
Pb-3	1.4	9.4	29.2	7.2	<1	<1	15.2	33.3
Pb-6	3.6	3.6	5.9	8.1	<1		10.2	34.8
Pb-9	3.1	10.1	4.2	9.0	1.0		4.1	<1
Pb-12	1.1	24.4	3.2	2.0	<1		1.0	37.4
Al-0	<1	<1	<1	1.0	<1	<1	<1	<1
Al-3	<1	<1	1.6	5.2	<1	1.6	2.3	5.4
Al-6	1.0	<1	1.1	5.6	<1		2.1	9.7
Al-9	1.0	<1	1.0	5.5	<1		1.0	10.7
Al-12	<1	<1	1.0	<1	<1		<1	14.6
Cu-0	<1	<1	<1	<1	<1	<1	<1	<1
Cu-3	<1	1.7	<1	<1	<1	<1	<1	<1
Cu-6	<1	<1	<1	<1	<1		<1	1.0
Cu-9	<1	1.0	<1	<1	<1		<1	1.0
Cu-12	<1	2.0	<1	<1	<1		<1	<1

TABLE 12.
Accumulated Miles and Hours[1] After One Year

Vehicle	Miles	Hours
1. M978 10-Ton Fuel Servicing Truck	197	85
2. M923 Cargo Truck	1707	57
3. M730A2 GM Carrier (Chaparral)	123	16
4. M1038ww 11/4-Ton Cargo Truck	545	na[2]
5. M998 11/4-Ton Cargo Truck	363	na
6. M3 Bradley Fighting Vehicle	652	na
7. M983 10-Ton Tractor Truck	686	132
8. M985 Cargo Truck with Crane	21	28
9. M1028A1 11/4-Ton Cargo Truck	1912	na
10. M813 5-Ton Fuel Servicing Truck	21	227
11. M543A2 5-Ton Wrecker Truck	149	17
12. **M2 Bradley Fighting Vehicle**	**75**	**na**
13. **M1009 $^3/_4$-Ton Utility Truck**	**1502**	**na**
14. **M1009 $^3/_4$-Ton Utility Truck**	**Blown Engine**	
15. **M35A2 $2^1/_2$-Ton Cargo Truck**	**1268**	**39**
16. **M730A2 GM Carrier (Chaparral)**	**320**	**29**

Average accumulated mileage = 636mi

[1] Control vehicles filled with MIL-A-46153 antifreeze highlighted in bold.
[2] "na" - not applicable

TABLE 13.
Compatibility Test Results

COMPATIBLE	INCOMPATIBLE
1.Tundra + Sta-Clean	1.Tundra + MIL-A-46153
2.Tundra + Eco-III	2.Tundra + Uni-Gard
3.MIL-A-46153 + Sta-Clean	3.MIL-A-46153 + Uni-Gard
4.MIL-A-46153 + Compleat	4.MIL-A-46153 + Eco-III
5.Eco-III + Sta-Clean	5.Tundra + Compleat
	6.Uni-Gard + Sta-Clean
	7.Eco-III + Compleat
	8.Eco-III + Uni-Gard
	9.Sta-Clean + Compleat
	10.Uni-Gard + Compleat

TABLE 14a.
Glassware Corrosion Test Results, ASTM D1384
weight change, mg/coupon[1]

Sample	Copper	Solder	Brass	Steel	Iron	Aluminum
Uni-Gard	+1	-7	-3	-1	-3	*-36*[2]
Sta-Clean	0	-18	-2	-1	-1	+2
Compleat	-2	-2	-5	8	-1	+2
Eco-III	-1	-1	+2	+1	*-69*	+2
Tundra[3]						
ASTM recommended maximum	**-10**	**-30**	**-10**	**-10**	**-10**	**-30**

[1] A plus sign (+) represents a weight gain.
[2] Italicized results indicate a test failure
[3] Not tested because of equipment failure

TABLE 14b.
Foam Test Results, ASTM D1881

Sample	Average Foam Vol	Break Time
Sta-Clean	48mL	2.0s
Compleat	118mL	*5.5s*
Eco-III	88mL	3.7s
Tundra	32mL	1.9s
Uni-Gard	47mL	4.2s
ASTM recommended maximum	**150mL**	**5.0s**

TABLE 15a.
Simulated Service Test Results, ASTM D2570
weight change, mg/coupon

Sample	Tundra	Compleat	Sta-Clean	Uni-Gard	Eco-III	ASTM recommended maximum
Copper	-4	-12	*-85*[1]	-13	-5	**-20**
Solder	-2	-2	*-331*	-1	-15	**-60**
Brass	-4	-9	-7	-2	-4	**-20**
Steel	-1	-2	-4	-1	-2	**-20**
Iron	-2	-1	-4	-1	-4	**-20**
Aluminum	-15	-4	-47	-3	-13	**-60**

[1] Italicized results indicate a test failure.

TABLE 15b.
Aluminum Pump Cavitation-Erosion Test Results, ASTM D2809

Sample	Rating Result[1]
Compleat	10
Sta-Clean	10
Uni-Gard	9
Tundra	_3_
Eco-III	_5_
ASTM recommended minimum	**8**

[1] ASTM rating system based on degree of erosion-corrosion of test water pump as determined by visual inspection. Ratings between ten (10) and eight (8) are considered passing. Ratings between seven (7) and one (1) are considered failing.